HYDROGEN
Safety Panel

Laboratory Hood Hydrogen Fire Incident

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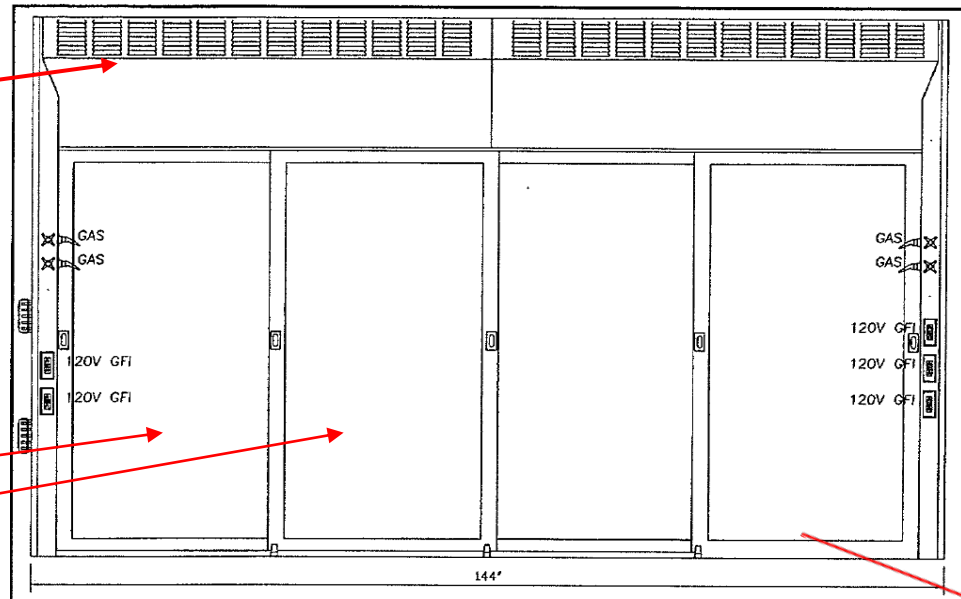
Presentation Outline

- Hood, Equipment, & Hydrogen Supply Description
- Incident Timeline and Damage Aftermath Photos
- Accident Investigation Team Analyses and Report
  - Plausible hydrogen release scenarios
  - Recommendations concerning hydrogen piping in lab
  - Recommendations concerning storage of extra materials in hood
- Extra Slides
  - Hydrogen Dispersion Calculations and Implications for initial partial volume deflagration in hood
  - Compressed Gas Cylinder Rupture and Blast Waves Pressures account for hood tempered glass door damage

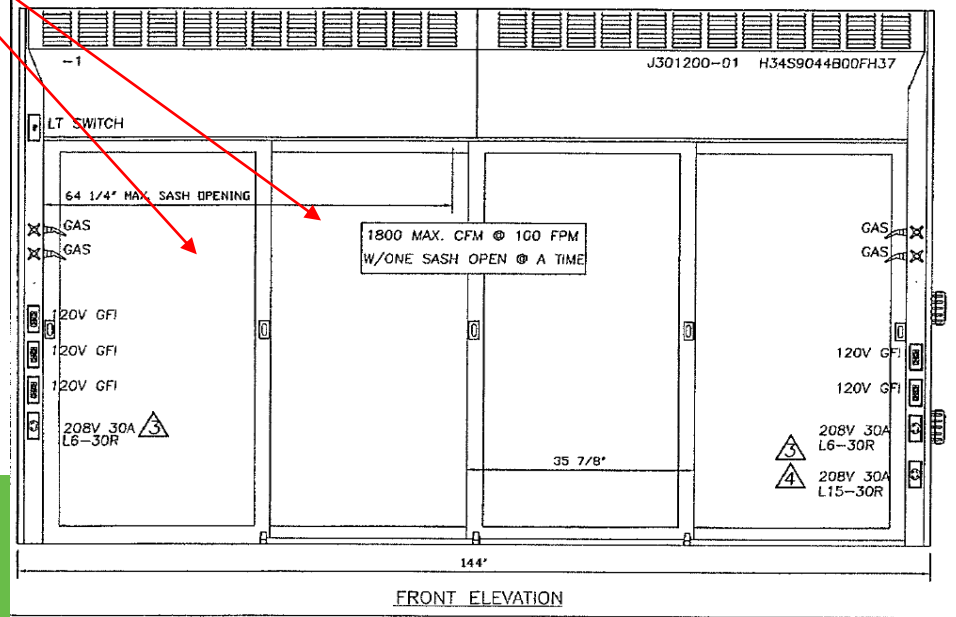
Walk-In Fume Hood: 12’Long x 5’wide x 7.5’ High

Ventilation Grill

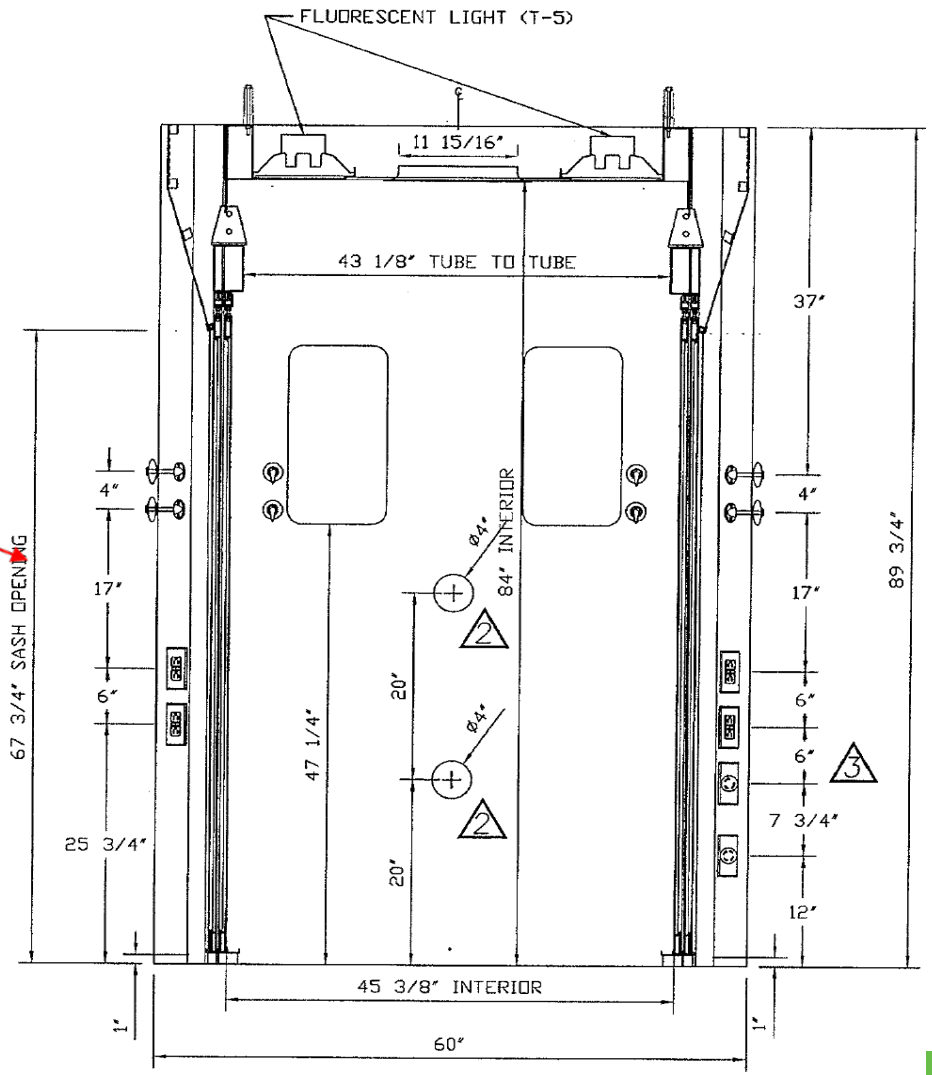
Tempered Glass Doors



REAR ELEVATION



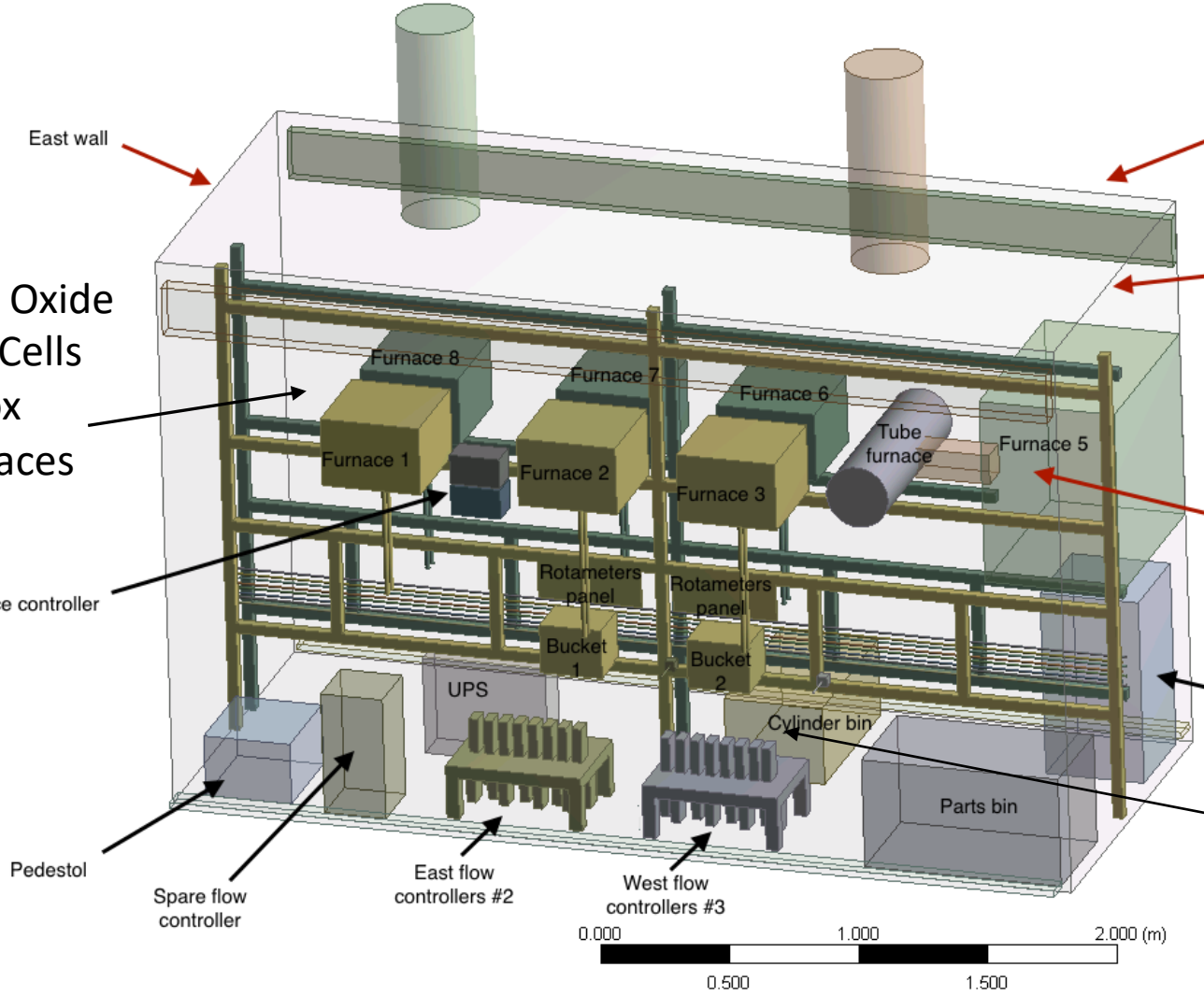
FRONT ELEVATION



RIGHT SECTION

HYDROGEN Safety Panel

Equipment in Fume Hood



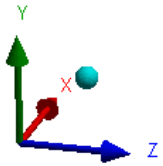
Solid Oxide Fuel Cells in Box Furnaces

Furnace controller

1,000 cfm exhaust flow rate;
About 3 air changes per minute

O2 generator

Open box of small compressed gas cylinders



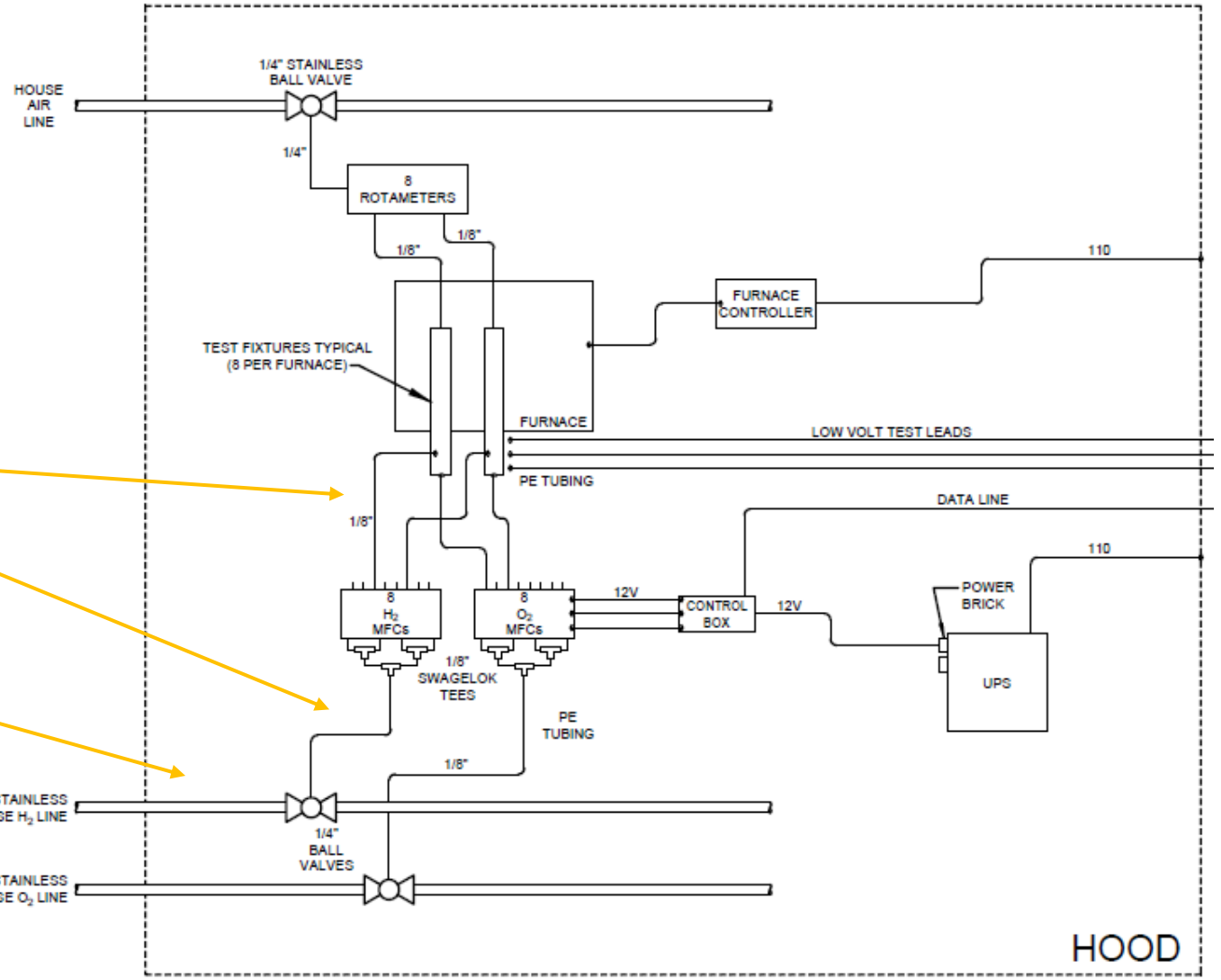
H_2 & O_2 Gas Flow to SOFC Test Cells in Furnaces

Polyethylene tubing

¼-inch stainless tubing

H2 from outside gas bottles

O2 from outside gas bottles



Hydrogen Supply Source

- Hydrogen source is lab exterior bottled gas storage rack dock.
- Piping from gas storage rack through 50 psig regulator to room with hood and to several other rooms and hoods.
- Excess flow valve on ½-inch line near storage rack, but setting is based on a ½-inch pipe break, not a breach of small diameter tubing at lower pressure far downstream.
- ¼-inch tubing in hood has solenoid valve that is automatically shut upon loss of hood exhaust flow, but not upon any H_2 leak detection in hood.

September 30, 2018 Incident Timeline

Time	Event
Prior to 2050	Cells operating normally in hood furnaces; 8 cells per furnace. Data from one cell showed some anomalies, but these were not thought to be related to the incident.
2058	Loss of operating cell signals in Hood 1. This presumably was due to the ignition of a hydrogen release in the hood.
2100 - 2118	PostDoc working in the basement of the building "heard a loud noise, then several lower noises, … lastly, a big noise again. All these happened within about 5 seconds." These noises were probably due to the rupture of the small compressed gas cylinders exposed to the hood fire.
2130	Hot combustion gases in hood exhaust duct melt flow control sensor. Temperature in room increasing because of combustion gases. Indications of fire spread to other combustibles in the hood.
2240	Hydrogen supply to building depleted. Total hydrogen consumed in event is about 1950 scf; corresponding to a flow rate of about 18 cfm.
2320	Night shift power operator making normal rounds heard a hissing sound in the lab. Upon opening the lab door, he saw debris, soot, and broken glass. He notified building and lab personnel of event.

Hood Damage Photos

More Hood Damage Photos

Doors removed to see interior damage

Suspected hydrogen release site:
Arrows denote possible release location and jet orientation

Minor Lab Damage Photos

Ceiling panels displaced by low overpressure in lab: could be caused by partial volume deflagration at ignition or by ruptured cylinder blast wave

Charring and smoke deposits on ceiling and light fixtures from burning plastics in hood.

Remains of Small Cylinders that were in Tote on Hood Floor

Location of Cylinder Tote Near Suspected Release Site

Edge of exemplar tote is directly under hydrogen tube fittings that were suspected release sites; Tote would have melted and burned; producing exposure fire directly on cylinders.

Accident Investigation Team Analyses & Report

- Five-person investigation team spent almost three months on investigation.
- Comprehensive examinations of damage and lab and SOFC data.
- Contracted analysis of hydrogen dispersion following initial release, and blast wave analysis of ruptured propane lecture bottle.
- Report evaluates eight possible incident scenario initiators and concludes that the hydrogen was most likely released from leaky polyethylene tube fitting, the degradation failure of polyethylene tubing, or possibly from an electrical malfunction fire in a mass flow controller.
- Report describes recommendations for preventing and/or mitigating possible future similar incidents.

Investigation Team Recommendations Re: Hydrogen

- Consider reducing / limiting the available flow and pressure of flammable gases to the extent practicable to conduct the related research. Flow and/or pressure restricting devices [near usage location] would be an effective engineered control to help bound plausible scenarios.
- Reevaluate the use of PE tubing near operations and activities involving elevated temperatures.
- Re-evaluate the engineered control to shut off the flow of hydrogen to the lab should the room exhaust be interrupted for 5 minutes or more.
- Improve consistency in updating labels for compressed gas lines inside fume hoods.

Investigation Team Recommendations on Temporary Storage of Compressed Gas Cylinders and Other Combustibles

- Reevaluate and/or strengthen policy related to storage of compressed gas cylinders near elevated temperature operations.
- Reevaluate and/or strengthen policy related to storage of general materials (e.g. totes with contents) inside hoods or ventilated enclosures containing elevated temperature related work.

Other Investigation Team Recommendations

- Seal/insulate the open annular spaces (around test cells) in the bottom surface of the furnaces to prevent hot objects from falling through.
- Evaluate and reconfigure / redesign the exhaust vent paths for SOFC and SOEC assemblies to eliminate Tygon® tubing.
- Consider strengthening the planning phases for facility modifications related to R&D work utilizing flammable or toxic gases (to allow reviews by pertinent Subject Matter Experts).
- Use consistent color coding of gas lines to prevent inadvertent connections of flammable gases, oxygen, and nitrogen.
- Label electrical wiring to prevent confusion on which furnaces are energized and which are out of service.

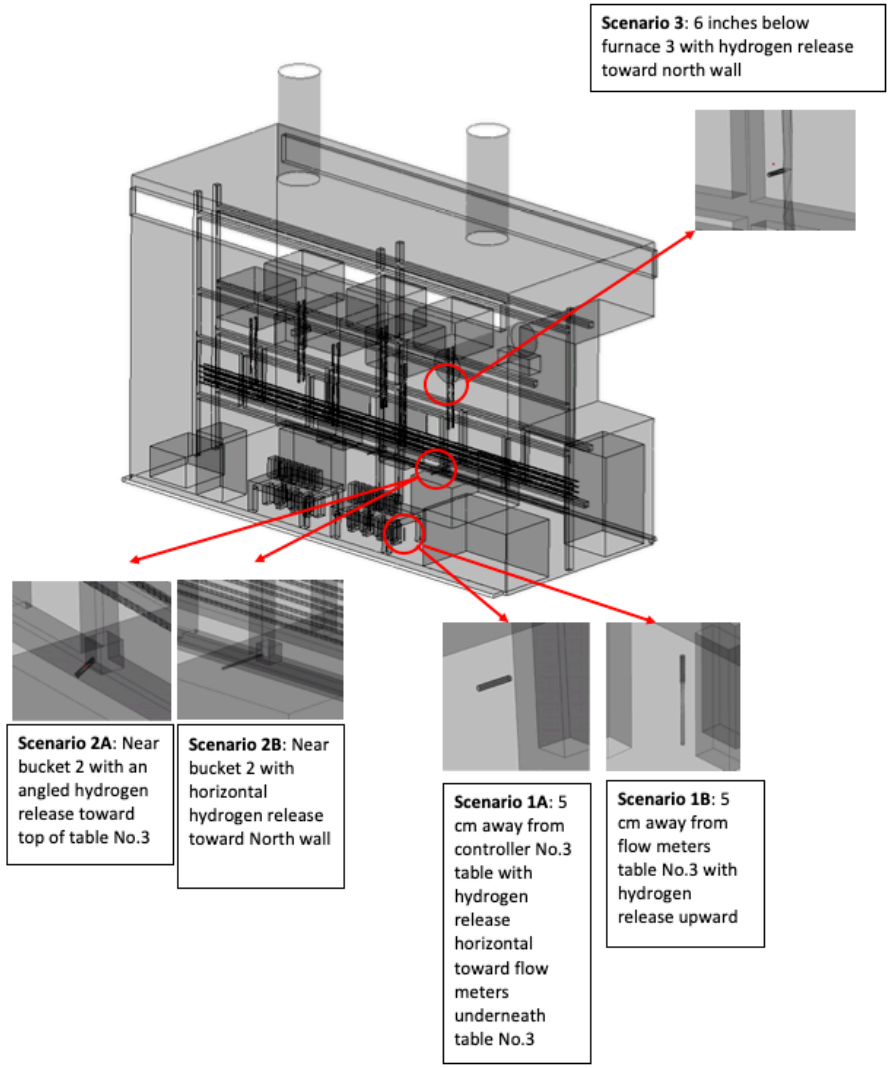
Extra Slides Follow as Backup/Elaboration

Walk-In Fume Hood

Incident Hood had 4 sliding doors on each side; exhaust ventilation duct on ceiling.

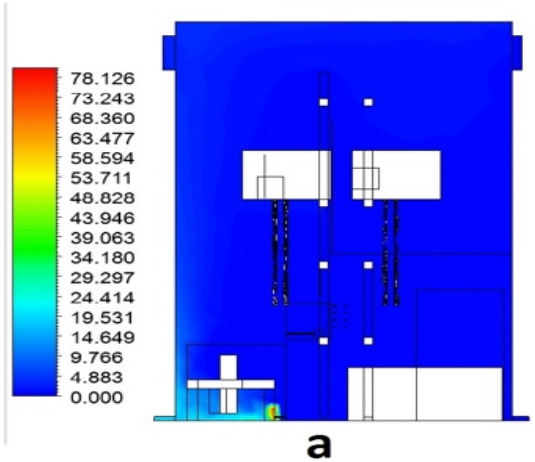
Hood Dimensions:
12’Long x 5’wide x 7.5’ High

Hydrogen Dispersion Calculations: Release Scenarios



- Calculations conducted with Fluent CFD Code
- 18 cfm hydrogen release in 5 different locations and directions
- Normal hood exhaust ventilation: 500 cfm through each of two exhaust ducts.
- Makeup air inflow under and above hood doors.
- CFD Output is hydrogen concentration distribution and volume of flammable region with H2 concentrations > 4% and > 6%

Hydrogen Dispersion Calculations: H2 Concentration Distributions



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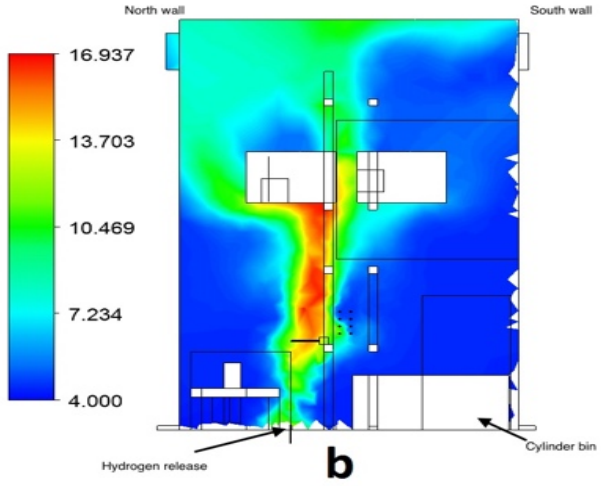

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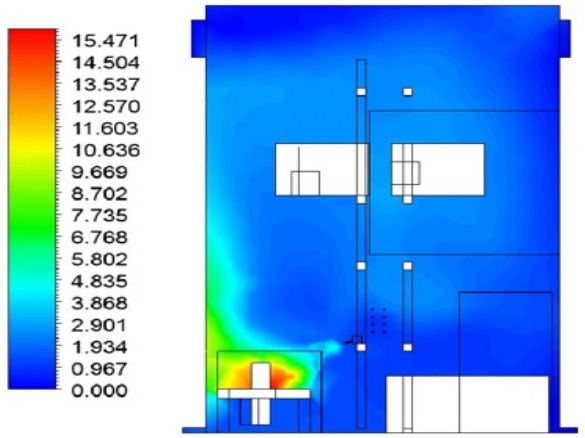

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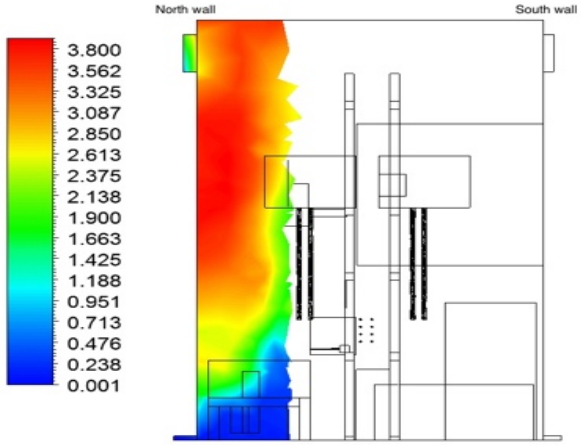

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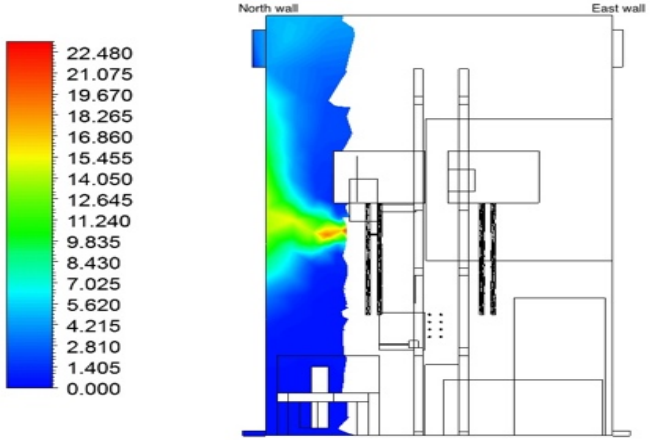

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Small flammable regions near release sites and extending up to furnace in one scenario.

H2 Dispersion Calculations: Flammable Region Volumes

Implication: hood ventilation effectively limits flammable region to small percent of hood volume, so that the partial volume deflagration at ignition will not produce pressures high enough to cause hood damage.

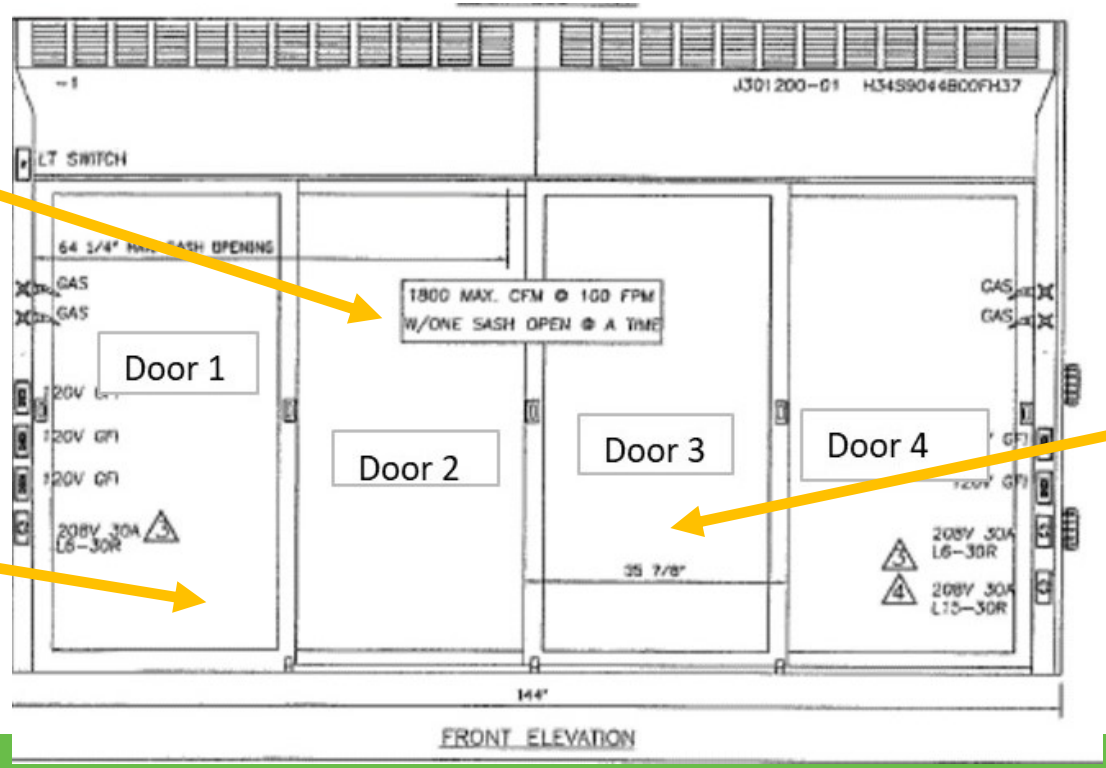
Scenarios	Volume of domain (m^3)	Volume of H_2>4% (m^3)	Volume of H_2>6% (m^3)	Average mole fraction in volume >4% (%)	Average mole fraction in volume >6% (%)	Average H_2 mole fraction (%)
1A	11.56	0.25	0.17	13.2	17.12	0.51
1B	11.56	1.86	0.52	6.69	11.19	1.34
2A	11.56	0.95	0.28	7.47	12.75	2.12
2B	11.56	1.86	0.62	7.64	15.32	1.52
3	11.56	0.71	0.18	7.69	11.94	1.04

Propane Lecture Bottle Blast Wave Analysis

- Estimated bottle rupture pressure due to fire exposure = 4.4 to 7.1 MPa.
- Blast wave pressures at doors shown in drawing below.
- Tempered Glass Breakage Pressure > 2.7 psig.
- Expect glass breakage on Door 2, but not on Doors 1, 3, 4.
- Consistent with door damage observations.

Door 2 blast pressures
= 6 to 20 psig.

Door 1 blast pressures
= 1.6 to 2.4 psig.



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